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Final Report DOD Project
Pollution Control in Aqueous Solution by Hydroponic Cultivation of Plants

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Primary Objectives:

The primary objectives of the project were to develop a research base to allow professionals in the Corps of Engineers to utilize plant cultivation methods to alleviate and remediate water pollution problems associated with various activities of the Army.

A two-fold approach was used. The first involved the design, construction and implementation of pilot scale studies to assess the abilities of plant species, both aquatic and terrestrial, to remove pollutants from low quality waters, such as stormwater runoff from contaminated sites and wastewater. This experimental approach offers the opportunity to quantitatively evaluate plant growth and biomass distribution including the accumulation of dissolved materials in plant organs such as roots, stems, leaves and flowers. The second approach involved utilization of simulated storm and waste water as a source of nutrients for growing a commercial greenhouse crop, in this case a floricultural crop.

Procedures Used:

Two sets of apparatus were designed and constructed for evaluation of aquatic and terrestrial plant species. The first system of cultivation was based on nutrient flow technology in which plants were cultivated in the absence of a supporting medium. Plant species targetted for their commercial potential as well as their ability to thrive under hydroponic cultivation included two cultivars of zinnia *(Zinnia elegans* 'Big Red' and 'Pumila') and two cultivars of marigold *(Tagetes erecta* 'Hero Yellow' and 'Safari Tangerine'. These plants were supplied nutrients from solutions which were formulated to conform to "typical" analyses of urban stormwater runoff and municipal

sewage treatment effluent. In Figure 1 can be seen the experimental setup just before the seedlings were placed into the hydroponics. The foam cubes that served as a germination matrix are being soaked in a various concentrations of paclobutrazol (0-180 ppm) commercially marketed as 'Bonsi' and uniconazole (1-60 ppm) commercially known as 'Sumagic'. These two chemical growth regulators have been reported to enhance root growth as opposed to shoot growth which was the rationale for their inclusion as plant pretreatments. These were being evaluated to determine if enhancing the root growth could result in greater uptake of nutrients and more thorough utilization of the storm and waste water.

QuickTime™ and a
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are needed to see this picture.

Figure 1. View of the hydroponic unit, flow nozzles, and hydroponic lines wrapped in black plastic to discourage algal

growth. Black covers were also placed over the catch basins for the same reason.

The second system of cultivation was based on a combination of trickling filter technology with constructed wetland methods. Small experimental modules were planted with cuttings of native black willow, *Salix nigra*, which were supplied with either simulated stormwater runofff or simulated secondary effluent.

Major Accomplishments and Results:

Greenhouse study with marigolds and zinnias.

Both marigold cultivars were well adapted to solution culture using the simulated storm and waste water representing both 'low' and 'high' nutrient regime. Greater flower bud formation occurred under the higher nutrient regime although flower production was adequate under the low nutrient regime. 'Big Red' zinnias had greater shoot dry weights but 'Pumila' produced more flowers. There was no advantage to triazole treatment of plants before placing them into the hydroponic system. There was no discernable and consistent pattern with respect to redirecting a proportionate amount of the growth into roots or in increasing plant nutrient uptake. Both triazoles but particularly paclobutrazol reduced plant height of both zinnias and marigolds but paclobutrazol and uniconazole at rates greater than 60 ppm reduced flower bud production. Both marigold cultivars 'Hero Yellow' and 'Safari Tangerine' but only zinnia cultivar 'Pumila' are good candidates for storm and waste water remediation as is evident in Figure 2 which shows the flowering response to the various treatments.

Figure 2. Profuse flowering of marigold cultivars 'Hero Yellow' and 'Safari Tangerine' in the foreground and less profuse flower development of zinnia cultivar 'Pumila' in the background.

Additional details concerning the results for height, biomass and distribution, flowering, nutrient uptake are detailed in the attached doctoral dissertation entitled, " Effects of Nutrition and Triazole Treatments on the Growth and Development of Marigolds and Zinnias" written by the doctoral student supported on the project, Arvazena Clardy.

Gravel hydroponics with black willow, sweetgum, and hibiscus.

The specific objectives of this experimental series with three species was to observe biomass accumulation and distribution,assess effects of nutritional treatments [SSW (low nutrient) vs SWW (high nutrient)], observe effects of water level in module (50% vs 95% saturated), and to determine quantities of solutes retained in plants.

The experiments conducted in the gravel hydroponic modules involved three species (black willow, sweetgum, and hibiscus)growth three plants in each module. There were seven replications of two water levels (low and high) and two nutrient fertility levels (stormwater and wastewater). The actual concentrations of the various plant nutrients in the simulated storm and waste waters can be seen in Table 1. Low treatment is synthetic stormwater and high treatment is synthetic wastewater. Nutrient concentrations were based on average values of nutrients in a stormwater runoff and effluent from a municipal water treatement plant after secondary treatment. The plant parts sampled were leaf, stem, and root for biomass accumulation and distribution.

Table 1. Concentration (ppm) of Selected Nutrients in Treatments Applied to Modules representing simulated storm (low) and waste (high) waters.

Nutrient	Low	High
N	4.9	19.6
P	3.0	12.0
K	4.0	16.0
Fe	1.0	1.0
Mn	0.2	0.2
B	0.1	0.1
Cu	0.01	0.01
Zn	0.01	0.01
Mo	0.005	0.005

Data for weight of plant (g), percent N, percent P, and percent K were examined to determine significant effects of the two water levels, two fertility levels (high or low), their Way and three-Way interactions. These are presented in Table 2.

In general, plant growth was good to excellent in both water level treatments and no nutrient deficiency symptoms were evident in any of the treatments, however, biomass accumulation was dependent on concentration of nutrients and water level in the root zone.

Table 2. Significance of Sources in Analysis of Data Derived from Experiments with 3 Species.

Sweetgum

	Water	Fert	Plpt	WxF	WxP	FxP	WxFxP
Wt (g)		*	**	**			**
N%	**	**	**	**	*	**	**
P%	**	**	**		**	**	*
K%		**	**			**	

Black Willow

	Water	Fert	Plpt	WxF	WxP	FxP	WxFxP
Wt (g)	**	**	**	**			*
N%		**	**			**	
P%		**	**		**	**	**
K%		**	**	**			

Hibiscus spp.

	Water	Fert	Plpt	WxF	WxP	FxP	WxFxP
Wt (g)		**					
N%		**	**			**	
P%		**	**			**	
K%	**	**	**	**		**	

For black willow, there was a significant effect of both water level and fertility on fresh weight, and only fertility on nitrogen percentage, phosphorus percentage and potassium percentage in the tissues (Table 2). There was also a significant effect of plant part on all of the parameters measured with the leaf tissues being the greatest accumulator of nitrogen (Table 3). Under the low fertility treatment, growth was less than under the high fertility treatment for all plant parts evaluated. The total biomass of plants in the high fertility treatment were approximately 2.5 times greater than under the low regime. A greater percentage of the plant biomass

was distributed in roots under the low fertility treatment (57.7%) than under the high fertility treatment (41.0%). The amount of nitrogen accumulated per plant under the high fertility treatment was 4.9 times greater than that under the low regime. This is probably and reflection of reduced availability and limited new growth driving demand for nitrogen uptake. Willow is a more efficient accumulator of nitrogen per unit plant weight under the higher nutrient regime than the low one. Visually, plants appeared healthy with no apparent symptoms of deficiency even under the low nutrient regime which indicates that black willow is a good candidate for wastewater remediation even under flooded or low nutrient conditions. The accumulation of nitrogen in leaves and the yearly leaf fall associated with onset of dormancy will result in that nitrogen being recycled in a 'slow release' form both in leaves and reallocation into stems and roots.

Table 3. Dry Weights and N contents of Black Willow

Pl

Fert	Plpt	Wt (g)	N%	N(g)	
Low	Leaf	12.3 (22.6%)	1.70	0.21	
	Stem	10.7 (19.7%)	0.32	0.03	
	Root	31.4 (57.7%)	0.11	0.03	
	Total	54.4			0.27
High	Leaf	40.5 (29.2%)	2.21	0.90	
	Stem	41.4 (29.8%)	0.50	0.21	
	Root	57.0 (41.0%)	0.35	0.20	
	Total	138.9			1.31

With sweetgum, water level affected N% and P% but not K% (Table 2). Fertility level affected not only weight significantly but also percentages of N, P, and K highly significantly. N% was also the most sensitive to interaction effects (Tables 2, 4). Unlike black willow, sweetgum did not have a larger percentage of its biomass in roots under the low nutrient regime with 41.5% and 40.4% for low and high water level respectively. Under high nutrients, 55.7% and 51.4% were distributed in roots for low and high water levels respectively. The greatest quantity of nitrogen was accumulated by leaves, followed by roots, and stem tissues for all four treatments

although roots and leaves had similar concentrations under the low fertility and high water level. The greatest quantity of nitrogen per plant was accumulated by those under the high fertility high water level followed by those under the high fertility, low water level.

Sweetgum appears to be well adapted to capturing and holding nitrogen under conditions when the water level is not high. When water levels are high, overall growth is adversely affected and nitrogen uptake at the low fertility level as well. If additional aeration is provided, this disparity in plant growth under the high level of water may be eliminated but sweetgum's utility for wastewater cleanup may best be confined to situations where the water level is lower if fertility is low. At the high fertility level, high water level, although tree growth was compromised by the high water level, nitrogen uptake was not with 1.62 g nitrogen per tree. The constraint that water level imposes on the versatility of sweetgum for use in flooded conditions may be immaterial if only nitrogen uptake is considered.

Table 4. Dry Weights and N contents of Sweetgum Plants After 14 Weeks in Modules

Fert	Water	Plpt	Wt (g)	N%	N(g)
Low	Low	Leaf	33.7	0.85	0.29
		Stem	52.5	0.06	0.03
		Root	61.1	0.25	0.15
		Total	147.3		0.47
Low	High	Leaf	31.2	0.92	0.29
		Stem	40.3	0.16	0.06
		Root	48.5	0.53	0.26
		Total	120.0		0.61
High	Low	Leaf	53.4	1.01	0.54
		Stem	74.7	0.09	0.07
		Root	161.2	0.31	0.50
		Total	289.3		1.11
High	High	Leaf	49.0	1.58	0.77

Stem	66.8	0.29	0.19
Root	122.5	0.54	0.66
Total	238.3		1.62

For hibiscus, water significantly affected only %K but fertility significantly affected all four parameters measured highly. Again, there was a highly significant effect of plant part on all three nutrients %N, %P, and %K. A highly significant pattern arose in the accumulation of all three nutrients as a function of plant part with %N and N(g) being shown in Table 5.

Table 5. Dry Weights and N contents of Hibiscus Plants After 13 Weeks in Modules

Fert	Plpt	Wt (g)	N%	N(g)
Low	Leaf	9.4	2.38	0.22
	Stem	7.5	0.80	0.06
	Root	6.1	0.86	0.05
	Total	23.0		0.33
High	Leaf	20.9	1.15	0.24
	Stem	19.8	0.45	0.09
	Root	27.7	0.70	0.19
	Total	68.4		0.52

The greatest proportion of biomass was accumulated by the leaf at the low fertility level but the differences between leaf (40.9%), stem (32.6%), and root (26.5%)were not dramatically different. At the high nutrient concentration, leaves and stems were similar but root biomass was greater (40.5%) and total biomass accumulated was three times larger than under the low nutrient regime. The accumulation of nitrogen per tree was not proportional to the increase in biomass at the higher nutrient level, with only 1.6 times the nitrogen accumulated at the higher versus the lower nutrient levels. Under the low nutrient regime, leaves were the predominate accumulator of nitrogen but under the higher nutrient regime, roots were also a major accumulator which suggests the possibility of leakage of nitrogen from roots back into the water system.

OVERALL DELIVERABLES

Three species were evaluated for their ability to grow, adapt to the physical environment, and accumulate nutrients under simulated storm and waste water conditions in gravel hydroponic units with two different water levels. The distribution of retained solutes in various plant parts was evaluated to determine the potential of accumulated nutrients for re-entry into the water system. Two cultivars each of two different ornamental species were evaluated in flow through systems in the greenhouse under simulated storm and wastewater conditions. These were also evaluated for their potential for horticultural crop production potential.

Major conclusions from the greenhouse hydroponic study:

- Marigold and Zinnia both grew and produced flowers under the high and low nutrient regimes but marigold was better adapted to the lower nutrient regime with both cultivars tested producing adequate numbers of flowers for a commercial crop. Only one cultivar of zinnia proved to be adequate. This underscores the need to evaluate multiple cultivars before conclusions regarding species adaptability can be made.

- Pretreating plants with triazole growth regulators did not enhance root growth and subsequent nitrogen uptake from the simulated waste streams.

Major conclusions from the gravel bed pilot study:

- In general, nutrient concentrations if low will severely limit biomass accumulation of plants.

- Shoot growth in particular in restricted in plants grown in simulated storm water.

- Root growth tends to be stimulated at high water levels.

- Black willow is adapted to an elevated concentration of nitrogen and has a high capacity to capture nitrogen. Capacity of plant to grow at low nutrient concentrations

  Sweetgum is well adapted to capture nitrogen from waste streams characterized by low nutrient levels but also is adapted to retain nitrogen in high nutrient level streams. It may also function better under higher water levels with better aeration.

- Hibiscus is adapted to both waste streams with low nutrients and those with low aeration.

- The best choice of species to optimize nutrient recovery may be influenced by the characteristics of the waste stream in terms of nutrient concentrations and depth of the stream. The choice of species and the characteristics of the waste stream will in turn influence the overall efficacy of the phytoremediation process. The duration and extent of the treatment required in relation to the flow and nutrient load will also be influenced by whether the system is set up to be growing season dependent or can accommodate year round treatment.

Theses and Dissertations Completed:

Clardy, Arvazena E. 1999. Effects of Nutrition and Triazole Treatments on the Growth and Development of Marigolds and Zinnias. Dissertation, Department of Plant and Soil Science, Alabama A&M University, Normal, AL 35762 (appended).

Publications:

Garton, S., C. T. Pounders, and T. G. Jensen. 1995. Assessment of Plant Performance in Constructed Wetland Modules: A New Experimental Approach. Proc. National Interagency Workshop on Wetlands, " Technology Advances for Wetlands Science" , New Orleans, LA, April 2-5, 1995.

Presentations at Professional Meetings:

Clardy, A. E., and S. Garton. 1995. Effects of nutrient and growth regulator treatment on growth and development of zinnias. Abstract presented at the 92nd Annual Meeting of the American Society for Horticultural Science, Montreal, Quebec, Canada, July 30-August 2, 1995.

Garton, S., C. T. Pounders, and C. A. Beyl. 1996. Water Pollution Control through Cultivation of Plants: A New Experimental Approach. Presentation at Phytoremediation Symposium, Huntsville, AL, March 1996.

Garton, S. 1997. Phytoremediation of Contaminated Waters. Presented at HMCBG Education Workshops for Science Teachers, US EPA, June 1997.

Appendix - Dissertation by Arvazena Clardy